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**Patentanmeldung Nr.    Patent application No.    Demande de brevet n°**

03006539.5

Der Präsident des Europäischen Patentamts;  
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets  
p.o.

**R C van Dijk**

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(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.  
If no title is shown please refer to the description.  
Si aucun titre n'est indiqué se référer à la description.)

Interferometric method and system

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Interferometric method and system

**Field of the invention**

The present invention relates to the field of interferometric measuring methods, for applications such as profile measurements, roughness measurements, plainness measurements, and measurements of the radius of curvature as well as to an arrangement for implementing this method.

**Background and prior art**

Interferometers are being increasingly used in a number of production processes to characterize and measure surfaces. Optical measuring devices of this kind are distinguished by a high degree of measuring accuracy. For manufacturing, it is desirable to make measurements without contacting the measured part to avoid damage. It is also desirable that measurements be fully automated.

A measuring device of this kind is the Laser Spot Scanning Interferometer (LASSI) described in U.S. Pat. No. 4,298,283 assigned to the assignee of the present invention, incorporated herein by reference. The underlying measuring principle is based on scanning the surface to be tested with two laser light beams which are simultaneously focused adjacent to each other onto the surface. During this process, the optical phase difference between the two light waves, which are reflected from the surface, changes linearly as a function of the height difference between the two laser spots on the surface. The phase difference is determined by phase shifting. For this purpose, an electro-optical light modulator is used which periodically shifts the phase difference between the two light waves by a fixed amount. At the same time, the intensity of the two interfering light beams is measured by a photodiode.

US Patent 5,392,116 which is assigned to the assignee of the present invention and is incorporated herein by reference, shows an interferometric phase measurement method which permits simultaneous signal evaluation.

The orthogonally polarized light beams with the phase difference are initially split by a beam splitter into several partial beam pairs which, by means of a lens are focused as parallel beams into a phase shifter, a polarizer, and an array of light sensors. Phase differences of the light beams create intensity differences between the beams received by the different light sensors. High measuring speed and accuracy are thus provided. When combined with means for directing two spatially separated orthogonally polarized beams on a surface, the method and apparatus can be used to determine height differences along the surface.

The present invention aims to provide an improved interferometric method and apparatus for enabling an increased precision of the interferometric measurement.

#### **Summary of the invention**

The present invention provides an improved interferometric method which enables to eliminate the material-dependent phase shift from the total phase shift of the reflected return beams. This material-dependent phase shift, which is also referred to as phase change on reflection (Fresnel phase shift), occurs when light is reflected from a dielectric or a metal and is dependent on the optical properties of the reflecting surface, in particular the index of refraction and the index of absorption and the optical properties of the ambient medium.

When the measurement beam is moved over different areas of the reflecting surface having different optical properties the material-dependent phase shift changes correspondingly and thus introduces a measurement error. By measuring the actual material dependent phase shift for the region onto which the measurement beam is currently directed this measurement error is eliminated.

The determination of the current material-dependent phase shift is performed based on a reflectivity measurement of the region on the reflecting surface onto which the measurement beam is directed. When the optical properties of the reference surface which reflects the reference beam is known, this enables to determine the material-dependent phase shift.

In accordance with a preferred embodiment of the invention both the measurement beam and the reference beam are reflected by the same surface. In this instance both the reflectivity of the region of the surface reflecting the measurement beam as well as the reflectivity of the surface region which reflects the reference beam need to be measured for the determination of the material-dependent phase shift.

In accordance with a further preferred embodiment of the invention the fringe visibility value which is delivered by a phase analyser is used to further improve the precision of the calculation of the material-dependent phase shift.

The present invention is particularly advantageous for measuring the topography of a surface which has a random distribution of areas having two different optical properties. An example for such a surface is AlTiC substrate ( $\text{Al}_2\text{O}_3$ -TiC) which consists of  $\text{Al}_2\text{O}_3$  in which TiC particles having randomly varying sizes and forms are embedded. Such an AlTiC substrate is used for the production of storage disk read/write heads. The interferometric method of the invention can thus be advantageously employed for measuring the topography of the read/write head surface in the production of such heads and for quality monitoring.

#### **Brief description of the drawings**

In the following preferred embodiments of the invention will be described in greater detail by making reference to the drawings in which:

Figure 1 shows a block diagram of an interferometric system,

Figure 2 is illustrative of the random distribution of areas having different optical properties on the measurement surface,

Figure 3 is a group of curves relating reflectivities to material-dependent phase shifts,

Figure 4 is a curve relating the reflectivity of the measurement beam to the material-dependent phase shift.

#### **Detailed description**

Figure 1 shows interferometric system 100 having a laser 102 for generating laser beam 104. Laser beam 104 passes through  $\lambda/2$ -plate 106 and is polarised by linear polarizer 108. The polarised laser beam 104 goes through beam splitter 110 and is divided into coherent light beams 112 and 114 by Wollaston-prism 116. Orthogonally polarised light beams 112 and 114 pass through lens 118, beam splitter 120, lens 122, and objective lens 126 before they are reflected from surface 128 to be measured. Light beam 112 is reflected from region 134 into return beam 130. Light beam 114 is reflected from region 136 on surface 128 into return beam 132.

A portion 138 is divided from light beam 112 by beam splitter 120 and directed through optics 142 onto photo diode 144. Photo diode 144 outputs a signal A which is proportional to the intensity of the light beam 112. Likewise beam splitter 120 provides portion 140 of light beam 114 which is directed through optics 142 to photo diode 146 which outputs a signal B which is proportional to the intensity of light beam 114.

Further, portion 172 of return beam 130 is provided by beam splitter 120 and directed through optics 150 to photo diode 152. Photo diode 152 outputs signal C which is proportional to the intensity of return beam 130. Likewise beam splitter 120 provides portion 148 of return beam 132 which is directed through optics 150 to photo diode 154 which provides signal D which is proportional to the intensity of return beam 132.



Wollaston-prism 116 and beam splitter 110 provide interference beam 158 which results from the interference of the return beams 130 and 132 to phase analyser 156. Phase analyser 156 outputs a signal which is proportional to the total phase shift  $\Delta\phi_T$  of return beams 130 and 132. Further, phase analyser 156 provides signal V which is the fringe visibility.

The signals A, B, C, D,  $\Delta\phi_T$  and V are inputted into signal processing component 160. By means of the signals A, B, C, D and V, signal processing component 160 eliminates the material-dependent phase shift  $\Delta\phi_m$  to provide the topography-dependent phase shift  $\Delta\phi_h$  ( $\Delta\phi_h = \Delta\phi_T - \Delta\phi_m$ ). By means of  $\Delta\phi_h$  the exact topography of the surface 128 can be determined.

Figure 2 shows a portion 162 of surface 128 (cf. figure 1). In the example considered here surface 128 belongs to a substrate which consists of a first material with embedded particles of a second material; the particles are randomly distributed and have random forms and shapes. For example the first material is  $Al_2O_3$  with embedded particles of TiC. Surface areas which are constituted by the first material are designated as  $a_1$  and surface areas which are constituted by the second material are designated as  $a_2$  in figure 2.

Light beam 112 is directed on portion 162 which results in a circular illumination pattern 164. Illumination pattern 164 covers a mixture of surface areas  $a_1$  and  $a_2$ .

Likewise light beam 114 impinges on portion 166 of surface 128 which is also composed of surface areas  $a_1$  and  $a_2$ . Light beam 114 creates illumination pattern 168 on portion 166.

The average reflectivities of the regions covered by illumination patterns 164 and 168, respectively, are used as a basis to determine the material-dependent phase shift  $\Delta\phi_m$ . This is illustrated in figure 3:

The diagram of figure 3 shows the relationship between the reflectivity  $R_1$  of the region on surface 128 which is covered by illumination pattern 164, the reflectivity  $R_2$  of the region on

surface 128 which is covered by illumination pattern 168 and the resulting material-dependent phase shift  $\Delta\phi_m$ . The reflectivity  $R_1$  is obtained by dividing signal C by signal A; likewise the reflectivity  $R_2$  is obtained by dividing signal D by signal B (cf. figure 1, single processing component 160). With the  $R_1$  and  $R_2$  reflectivity values the material-dependent phase shift is determined and subtracted from the total phase shift  $\Delta\phi_T$  which is provided by phase analyser 156 (cf. figure 1).

The diagram of figure 3 can be obtained by a series of calibration measurements. Alternatively the diagram of figure 3 can be obtained by means of a mathematical model:

$$\Delta\phi_h = \Delta\phi_T - \Delta\phi_m$$

$$\Delta\phi_m = \arcsin(\alpha\beta)$$

$$\alpha = \frac{r_1 r_2 \sin(\phi_2 - \phi_1)}{|(r_1)^2 - (r_2)^2|}$$

$$\beta = \frac{1}{2V} \frac{(R_1)^2 - (R_2)^2}{(R_1)^2 + (R_2)^2} \quad \text{where}$$

$\Delta\phi_h$  : topography - dependent\_phase\_shift

$\Delta\phi_T$  : total \_ phase \_ shift

$\Delta\phi_m$  : material - dependent\_phase\_shift

$r_1$  : reflection\_coefficient\_of\_material\_1

$r_2$  : reflection\_coefficient\_of\_material\_2

$\phi_1$  : phase\_shift\_caused\_by\_reflection\_from\_first\_material

$\phi_2$  : phase\_shift\_caused\_by\_reflection\_from\_second\_material

$R_1$  : reflectivity\_of \_ first \_ region

$R_2$  : reflectivity\_of \_ second \_ region

$V$  : fringe \_ visibility

It is to be noted that  $\alpha$  is a constant for a given pair of materials. This is because the reflection coefficient  $r_1$  of the first material, the reflection coefficient  $r_2$  of the second material as well as the material-dependent phase shift  $\phi_1$  caused by reflection from the first material and the material-dependent

phase shift  $\phi_2$  caused by reflection from the second material are material constants. Thus  $\alpha$  only needs to be calculated once for a given material pair which constitutes a surface and can be stored for future reference.

The value of  $\beta$  needs to be recalculated for each position of the illumination patterns 164 and 168 as the reflectivities  $R_1$  and  $R_2$  can randomly vary between the values  $|r_1|^2$  and  $|r_2|^2$ .

As apparent from the above mathematical model  $\Delta\phi_h = \Delta\phi_T$ , if  $R_1 = R_2$ . Hence, when  $R_1 = R_2$  the total phase shift does not require a correction. This enables one embodiment, where a height value is only outputted, when  $R_1 = R_2$  as in this instance no correction of the total phase difference is needed.

Alternatively only light beam 112 serves as a measurement beam whereas light beam 114 serves as a reference light beam. In this instance light beam 114 is reflected from a reference surface having known optical properties. In this case only the reflectivity  $R_1$  needs to be measured for the calculation of  $\beta$  and  $\Delta\phi_m$ .

This situation is illustrated in the diagram of figure 4 where the diagram of figure 3 is reduced to a single curve 170 which relates the measured reflectivity  $R_1$  to the material-dependent phase shift  $\Delta\phi_m$ . When the illumination pattern 164 of light beam 112 covers a region which only consists of Al<sub>2</sub>O<sub>3</sub> the additional phase shift  $\Delta\phi_m$  is about 0 whereas when illumination pattern 164 covers a region which only consists of TiC the phase shift  $\Delta\phi_m$  is about  $0.106 \pi$  which corresponds to a virtual height of about 16 nanometres for a measurement wavelength of 633 nanometers. This way a measurement error of up to 16 nanometers can be eliminated in the example considered here.

L I S T O F R E F E R E N C E N U M E R A L S

100	interferometric system
102	laser
104	laser beam
106	$\lambda/2$ -plate
108	polariser
110	beam splitter
112	light beam
114	light beam
116	Wollaston-prism
118	lens
120	beam splitter
122	lens
126	objective lens
128	surface
130	return beam
132	return beam
134	region
136	region
138	portion
140	portion
142	optics
144	photo diode
146	photo diode
148	portion
150	optics
152	photo diode
156	phase analyser
158	interference beam
160	signal processing component
162	portion
164	illumination pattern
166	portion
168	illumination pattern
170	curve
172	portion

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C L A I M S

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1. An interferometric method for measuring a height of a first region (164, 168) on a first surface (128, 162, 166), the first surface having first areas ( $a_1$ ) having first optical properties and second areas ( $a_2$ ) having second optical properties, the method comprising the steps of:
  - generating of first and second coherent light beams (112, 114),
  - reflecting at least the first coherent light (112) beam from the first region (164) into a first return beam (130) and reflecting the second coherent light beam (114) from a second region into a second return beam (132),
  - measuring at least a first reflectivity ( $R_1$ ) of the first region,
  - determining a topography-dependent phase shift ( $\Delta\phi_h$ ) of the first and second return beams for the height measurement based on the first reflectivity.
2. The interferometric method of claim 1, further comprising comparing of the first reflectivity and a second reflectivity ( $R_2$ ) of the second region, whereby the total phase shift ( $\Delta\phi_T$ ) of the first and second return beams is only used for the height measurement, if the first and second reflectivities are equal.
3. The interferometric method of claims 1 or 2, whereby the topography-dependent phase shift is determined based on the first and/or second optical properties of the first and/or second areas covered by the first region.
4. The method of claims 1, 2 or 3, the topography-dependent phase shift being determined by means of a curve (170) relating at least the first reflectivity to a material-

dependent phase shift ( $\Delta\phi_m$ ) being dependent on the first and second optical properties.

5. The interferometric method of any one of the preceding claims 1 to 4, the second region being located on a second surface, the second surface being a reference surface having known optical properties.
6. The interferometric method of any one of the preceding claims 1 to 4, the second region (168) being located on the first surface, and further comprising measuring of a second reflectivity ( $R_2$ ) of the second region, whereby the topography-dependent phase shift is determined based on the first and second reflectivities.
7. The interferometric method of any one of the preceding claims 1 to 6, whereby a fringe visibility ( $V$ ) is used for determining of the topography-dependent phase shift.
8. The interferometric method of any one of the preceding claims 1 to 7, the topography-dependent phase shift being determined as follows:

$$\Delta\phi_h = \Delta\phi_T - \Delta\phi_m$$

$$\Delta\phi_m = \arcsin(\alpha\beta)$$

$$\alpha = \frac{r_1 r_2 \sin(\phi_2 - \phi_1)}{|(r_1)^2 - (r_2)^2|}$$

$$\beta = \frac{1}{2V} \frac{(R_1)^2 - (R_2)^2}{(R_1)^2 + (R_2)^2}$$

where

$\Delta\phi_h$  : topography - dependent\_phase\_shift

$\Delta\phi_T$  : total \_ phase \_ shift

$\Delta\phi_m$  : material - dependent\_phase\_shift

$r_1$  : reflection \_ coefficient \_ of \_ first \_ area

$r_2$  : reflection \_ coefficient \_ of \_ second \_ area

$\phi_1$  : phase \_ shift \_ caused \_ by \_ reflection \_ from \_ first \_ area

$\phi_2$  : phase \_ shift \_ caused \_ by \_ reflection \_ from \_ second \_ area

$R_1$  : reflectivity \_ of \_ first \_ region

$R_2$  : reflectivity \_ of \_ second \_ region

$V$  : fringe \_ visibility

9. Computer program product, in particular digital storage medium, comprising program means for determining a height of a first region on a first surface, the first surface having first areas having first optical properties and second areas having second optical properties, the program means being adapted to perform the steps of:

- determining a topography-dependent phase shift by subtracting a material-dependent phase shift being dependent on the first and second optical properties from a total phase shift of reflected first and second coherent light beams,
- calculating of the material-dependent phase shift based on the first and second optical properties and at least based on measurement data of a first reflectivity of the first region.

10. The computer program product of claim 9, the program means being adapted to perform the following calculations:

$$\Delta\varphi_h = \Delta\varphi_T - \Delta\varphi_m$$

$$\Delta\varphi_m = \arcsin(\alpha\beta)$$

$$\alpha = \frac{r_1 r_2 \sin(\varphi_2 - \varphi_1)}{|(r_1)^2 - (r_2)^2|}$$

$$\beta = \frac{1}{2V} \frac{(R_1)^2 - (R_2)^2}{(R_1)^2 + (R_2)^2}$$

where

$\Delta\varphi_h$  : topography - dependent\_phase\_shift

$\Delta\varphi_T$  : total \_ phase \_ shift

$\Delta\varphi_m$  : material - dependent\_phase\_shift

$r_1$  : reflection\_coefficient \_ of \_ first \_ area

$r_2$  : reflection\_coefficient \_ of \_ second \_ area

$\varphi_1$  : phase \_ shift \_ caused \_ by \_ reflection \_ from \_ first \_ area

$\varphi_2$  : phase \_ shift \_ caused \_ by \_ reflection \_ from \_ second \_ area

$R_1$  : reflectivity \_ of \_ first \_ region

$R_2$  : reflectivity \_ of \_ second \_ region

$V$  : fringe \_ visibility

11. An interferometric system for measuring a height of a first region (164, 168) on a first surface (128, 162, 166), the first surface having first areas ( $a_1$ ) having first optical properties and second areas ( $a_2$ ) having second optical properties, the interferometric system comprising:
  - means (102, 116) for generating of a first coherent light beam (112) for reflecting the first coherent light beam from the first region (164) into a first return beam (130),
  - means (102, 116) for generating of a second coherent light beam (114) for reflecting of the second coherent light beam from a second region,
  - means (142, 144, 150, 152) for measuring of at least a first reflectivity ( $R_1$ ) of the first region,
  - means (156, 160) for determining the height based on a phase shift of the first and second return beams and based on the first reflectivity.
12. The interferometric system of claim 11, the means for determining the height being adapted to compare the first reflectivity and a second reflectivity ( $R_2$ ) of the second region, whereby a height value is only outputted if the first and second reflectivities are equal.
13. The interferometric system of claims 11 or 12, further comprising means (156) for providing a fringe visibility ( $V$ ), the means for determining the height being adapted to use the fringe visibility for the height determination.
14. The interferometric system of claims 11, 12 or 13, the means for determining the height being adapted to determine a height-dependent phase shift as follows:



$$\Delta\varphi_h = \Delta\varphi_T - \Delta\varphi_m$$

$$\Delta\varphi_m = \arcsin(\alpha\beta)$$

$$\alpha = \frac{r_1 r_2 \sin(\varphi_2 - \varphi_1)}{|(r_1)^2 - (r_2)^2|}$$

$$\beta = \frac{1}{2V} \frac{(R_1)^2 - (R_2)^2}{(R_1)^2 + (R_2)^2}$$

where

$\Delta\varphi_h$  : *height - dependent\_phase\_shift*

$\Delta\varphi_T$  : *total \_ phase \_ shift*

$\Delta\varphi_m$  : *material - dependent\_phase\_shift*

$r_1$  : *reflection \_ coefficient \_ of \_ first \_ area*

$r_2$  : *reflection \_ coefficient \_ of \_ second \_ area*

$\varphi_1$  : *phase \_ shift \_ caused \_ by \_ reflection \_ from \_ first \_ area*

$\varphi_2$  : *phase \_ shift \_ caused \_ by \_ reflection \_ from \_ second \_ area*

$R_1$  : *reflectivity \_ of \_ first \_ region*

$R_2$  : *reflectivity \_ of \_ second \_ region*

$V$  : *fringe \_ visibility*

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The invention relates to an interferometric method for measuring a height of a first region (164, 168) on a first surface (128, 162, 166), the first surface having first areas ( $a_1$ ) having first optical properties and second areas ( $a_2$ ) having second optical properties, the method comprising the steps of:

- generating of first and second coherent light beams (112, 114),
- reflecting at least the first coherent light (112) beam from the first region (164) into a first return beam (130) and reflecting the second coherent light beam (114) from a second region into a second return beam (132),
- measuring at least a first reflectivity ( $R_1$ ) of the first region,
- determining a topography-dependent phase shift ( $\Delta\varphi_h$ ) of the first and second return beams for the height measurement based on the first reflectivity.

(figure 1)

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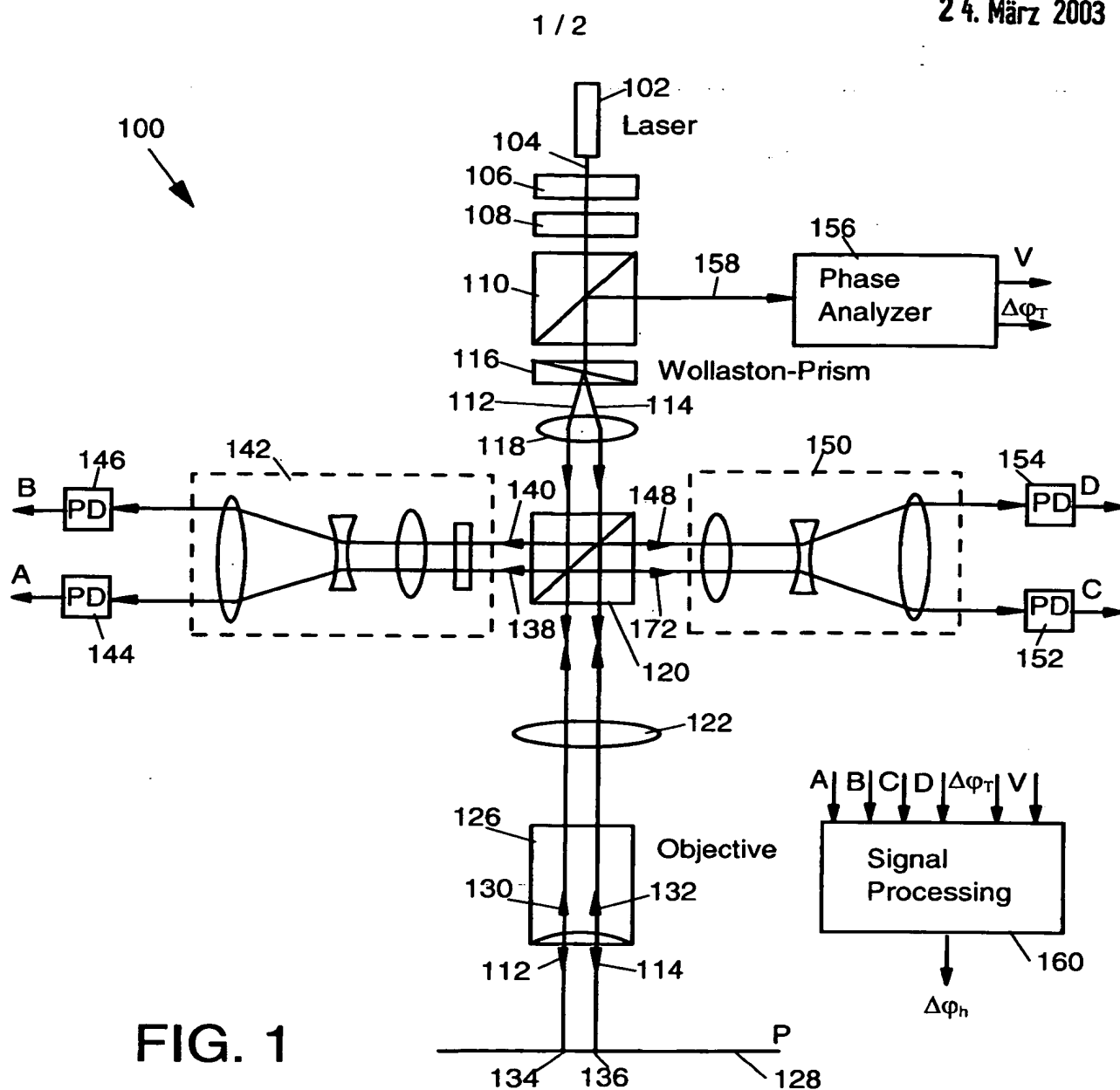


FIG. 1

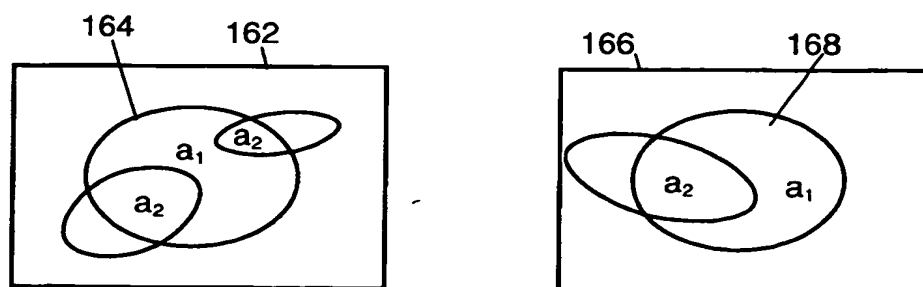


FIG. 2

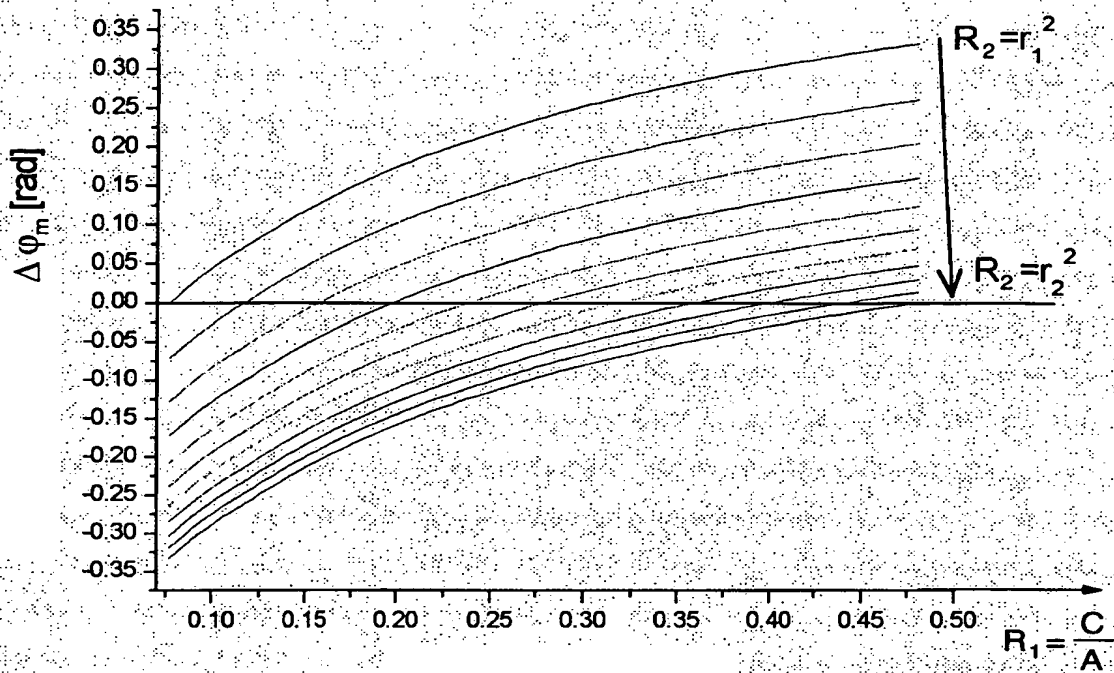


FIG. 3

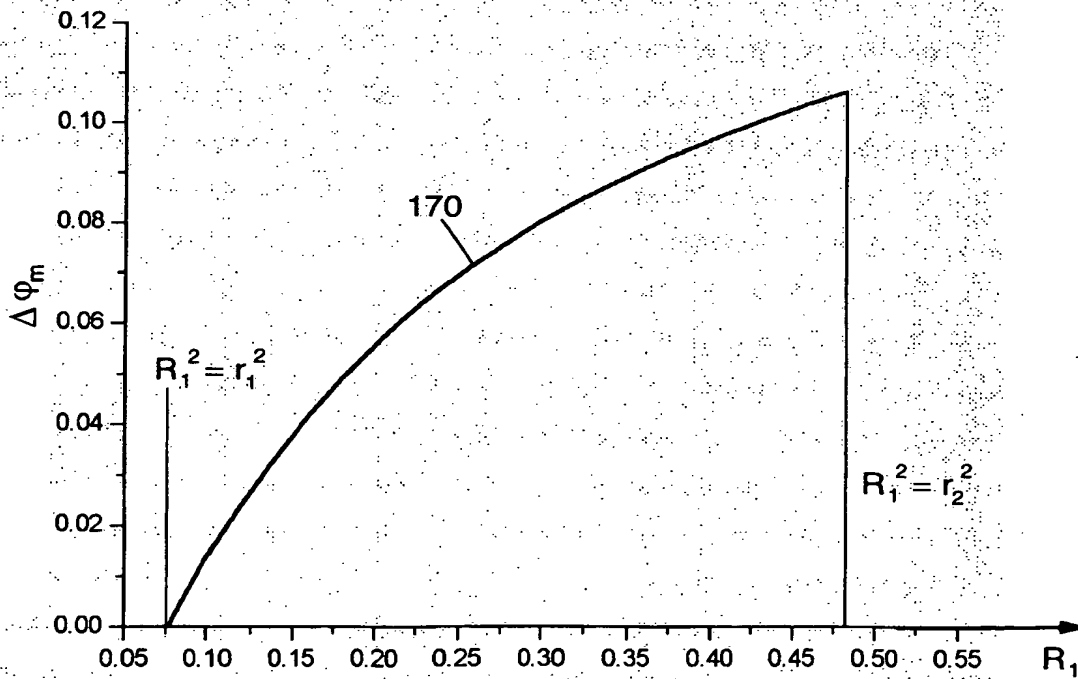


FIG. 4